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A RESEARCH STUDY ON THE DESIGN OF A 2:1 REDUCTION PRINTER LENS

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CONTRACT [redacted]

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ABSTRACT

This report covers the results of an optical design study for the development of a diffraction limited enlarging/reduction lens with a 16 inch equivalent focal length, F/2.0 effective relative aperture and a magnification ratio of 2 to 1 (object to image aspect).

This design development program was conducted under the auspices of Government Contract Number [redacted]

PREFACE

The relatively rapid advances in the state of the art of information gathering devices such as films, IMC systems, telemetry and photoelectric detectors requires the development of practical optical systems designs capable of transferring object information content to an image with a very minimum of information deterioration or loss, irrespective of the particular system's application.

A most ambitious endeavor would be the development of optical systems whose performances are not the critical or limiting factor in information acquisition.

A stigmatic optical system, the essence of geometrical perfection, would be achieved only when a ray bundle originating at an object point will converge and render a point in the image space. Ironically, the attainment of geometric perfection is not possible since the image of an ideal object point has a finite extent according to the laws of diffraction, perforcely setting a limit on the transferred information content.

Therefore, the problem of obtaining the maximum information must be solved by setting the most practical goal. That goal is the design of a diffraction limited system.

It is fitting at this point to define the term "diffraction-limited system". Such a system might well be defined as one in which the image quality is substantially determined by the diffraction effects, the effects of residual geometrical aberrations being small by comparison.

It is significant to note that should the residual geometrical aberration be identically zero, the stigmatic case would not be fulfilled. Therefore, it is pointless to attempt geometrical perfection when, from a value engineering aspect, finite aberrations are tolerable but indistinguishable in terms of image quality. In fact, the subject of diffraction theory of image formation by a system of lenses is a most valuable adjunct to the method of geometrical ray tracing in understanding the fundamental nature of defects in optical systems and finding methods of ameliorating them.

The effects of diffraction and its resultant effects on image quality were first investigated by G. B. Airy about 1834, and led to the result that an image of an ideal object takes the form of a strong, central condensation of light, surrounded by a series of concentric rings of light of increasing diameter of low and rapidly diminishing intensity.

It was shown subsequently that 85 percent of the transmitted energy appeared in the central condensation, the remaining 15 percent distributed in the surrounding intensity maxima.

The linear extent of the central maxima, or Airy disc, is wholly dependent upon the effective relative aperture of the optical system. The relative aperture reaches a physical limit when the rays fall at grazing incidence on the image plane. In an F/2.0 system operating at 2:1 conjugates with negligible aberrations, the Airy disc or point spread function is approximately 2.2 mu.

If it can be shown that approximately 80 percent of the transmitted energy is contained within the first dark ring of the Airy disc, the diffraction limited case has been fulfilled.

In this report, we present the results of three parallel design approaches to achieve this condition. One design has proved to be successful. Its development represents an important advance in enlarging/reduction lenses suitable for the purposes of this study and some future application.

SECTION I

INTRODUCTION

The objective of this study is the development of a feasible optical design which will meet the following specifications:

1) The design target parameters shall be:

A. An effective focal length of 16 inches or greater.

B. An effective relative aperture of F/2.0.

C. An object format size of 18 in. X 18 in.

D. An image format size of 9 in. X 9 in.

E. A magnification ratio of 2 to 1 (object to image).

F. An achromatic correction within the spectral range of 486.1 mu through 656.3 mu.

G. Distortion not to exceed 0.5mm over the entire format.

H. An axial transmittance of 60% or greater.

I. A relative illumination at the format corners of 60% or greater.

2) Resolution over the entire format to be diffraction limited within the specified spectral range, under low contrast conditions.

3) The achievement of these specifications shall result in a paper design which is capable of manufacture such that the prototype

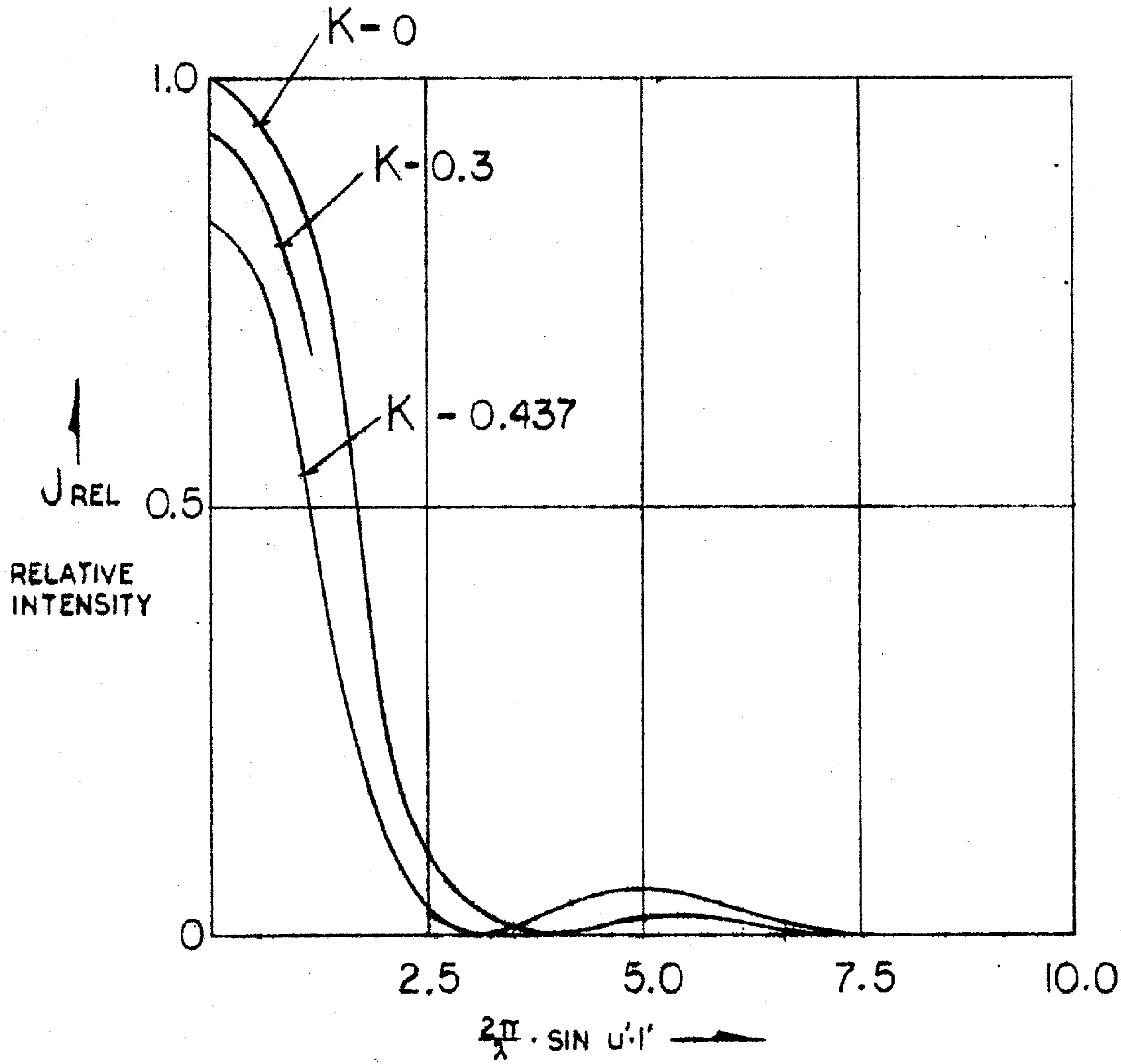
performance shall meet the specifications within reasonable tolerance.

Despite the fact that catadioptric systems have various desirable features, it was our studied opinion that such an approach will not meet the specifications.

If the catadioptric system is considered from the standpoint of Physical Optics, it can be shown that a pupil function can be constructed such that the image pattern irradiance falls from a maximum at the center to zero in an arbitrary small radius remaining zero to an arbitrary large radius. Hence, it would seem that the minimum resolvable angle could be reduced indefinitely.

In practice, however, a practical limitation results from the fact that as the central spot or Airy disc maximum is made smaller, the amount of light falling in it also becomes smaller and ultimately zero.

As the diameter of the central obscuration approaches that of the lens, the diameter of the first dark ring of the diffraction pattern approaches some six tenths of that system without obscuration. At the same time, the maximum irradiance in the first bright ring around the central spot, expressed as a function of the irradiance at the central spot, increases eight-fold, making more difficult the problem of resolving a faint source from a bright one. (Figure 1A)



Light distribution in the focal plane of a system with pupil shaped as an annulus. K is a ratio = diameter of the obscuring center disc divided by the diameter of the full pupil.

(According to Steel)

FIG. 1 A

Therefore, the utilization of a catadioptric system, in view of the specified low contrast object conditions, would be tantamount to performance failure. The all-refractive system, then, becomes the object of basic study.

Conventional enlarging/reduction printer lenses are generally characterized by their quasi-Gaussian form of relatively short focal lengths as compared to object height. The Gauss type optical designs are essentially symmetrical, each element becoming more meniscus in shape towards a mid stop position. In such systems, the lateral aberrations can be easily made quite small. Once these residuals are small, the designer has considerable freedom to influence the transverse aberrations.

When the focal length becomes large with respect to object size, the development of a well corrected printer lens becomes a problem whose magnitude is several times more difficult. The Gauss type design becomes unsuitable in such a situation, calling for a rather unconventional approach.

Therefore, the initial design philosophy adopted by [redacted] consisted of several parallel approaches specifically oriented toward the development of a plausible front and rear conjugate system, each separately designed and evaluated. They would ultimately be combined to form the desired 2:1 reduction printer lens.

An investigation of three distinct conjugate systems were considered which might approach the parameters.

1) A flat field achromat containing a Triplet on the long conjugate and a Tessar on the short conjugate.

2) A well corrected compact telephoto and a front aperture stop infinity objective resembling the Petzval form.

3) A flat field semi-apochromat composed of two front aperture stop infinity Petzval objectives.

The Triplet and Tessar, each having been originally designed as conventional infinity objectives of moderately high speed, were redesigned to adapt to the object and image conjugates respectively, and modified such that natural stop position would be in the neighborhood of the front vertex of each system.

When combined, this form exhibited an objectionable amount of oblique spherical aberration and sagittal curvature of field when an axial spherical solution was achieved.

The investigation continued until it was determined that several additional elements, and perhaps an achromatic aspheric corrector plate at the stop plane, would be required to correct the imagery to the extent necessary to meet the specifications. Hence, this form was abandoned and did not reach the final design stage.

The compact telephoto and modified Petzval form investigation appeared more fruitful from the onset. Since the stop position is near the front convergent member and corrected for coma over the field, each system was designed separately to an exceptionally fine correction.

When combined, however, a serious offense against the sine condition resulted, which manifested itself in positive sagittal curvature of field and a large amount of positive distortion. The higher order residuals of this form could not be conveniently balanced. It became apparent at this point that a near hemi-symmetrical approach was necessary.

It was decided to concentrate the design efforts on a Petzval form objective on the front and rear conjugates. The Petzval is a basic form in which achromatism is easily achieved. Moreover, this form can be designed to render exceptionally fine off axis imagery and with a Smythe-Piazzi field flattener, a flat field diffraction limited system can be achieved.

Section II contains the complete technical discussion of this development.

SECTION II

Technical Discussion
Semi-Apochromatic Reduction Lens

The design development of this reduction printer lens was obtained by initially designing a well corrected flat-field front aperture stop infinity objective composed of common glasses, in which the elements are compounded and split several times.

This particular objective, whose configuration resembles a derivative of the Petzval form, has all spherical surfaces which are extremely mild. These successive shallow curvatures contribute a minimum of higher order aberration as well as afford a discreet correction distribution for the simultaneous correction of third and fifth order aberrations and balancing of the higher orders.

A field flattener lens near the focal plane affords an anastigmatic image at high apertures.

Since the Petzval lens is substantially corrected for secondary color, a particularly troublesome aberration, it was a promising starting point for this investigation.

In general, the Petzval form exhibits considerable oblique zonal spherical aberration when an axial spherical solution is achieved. It has been found, however, that successive shallow surfaces, coupled with relatively long airpaths may be successfully utilized to control the surface by surface oblique incidence angles; the principal offender in introducing oblique spherical.

Since the system was designed with a front aperture stop, the entrance pupil is substantially at the front vertex of the leading convergent lens group. With the entrance pupil in this location, the designer has considerable freedom to correct the chromatic aberrations without altering the general characteristics of the monochromatic aberrations. Pronounced changes in the front convergent group to influence spherical aberration and coma do not affect its contribution to field curvature and astigmatism.

The combination of high speed and diffraction limited performance is particularly difficult to achieve along with apochromatic color correction. The utilization of a limited spectral window, however, reduces the color problem significantly. In fact, the system is to be utilized with a virtually monochromatic light source, eliminating the color problem completely.

Despite this fact, it was decided to pursue the design to ultimately obtain a top quality achromat or semi-apochromat in order to extend the system's capability as a printer lens. Whenever the resolution requirements demanded the utmost in performance it would be used as a monochromat.

The optimum spectral range of correction was extended to cover a thousand Angstroms (452.5 mu through 552.5 mu), in the region of strong spectral response of the low voltage mercury source or germicidal lamp.

The front aperture stop infinity objective described above has a 32 inch effective focal length, a relative aperture of F/3.0 and covers a format of 9 inches by 9 inches.

This objective becomes the basic building block or short conjugate module of the reduction printer lens.

Since a 2 X reduction is required in this application, a direct scale-up of the short conjugate module to 64 inch effective focal length, preserving the same effective aperture, yields an infinity objective having a relative aperture of F/6.0 covering an 18 inch by 18 inch format. This scale-up objective becomes the long conjugate module.

The entrance pupil diameter of each conjugate being identical, allows the former and latter modules to be attached to each other about the effective aperture stop position. The stop in this position is said to be telecentric. (See Figure 1B)

When combined in this fashion, the principle of symmetry substantially reduces the residual lateral aberrations (Coma, Distortion, and Lateral Color) to near zero.

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The resultant system becomes a 16 inch EFL F/2.0 2:1 reduction printer lens. The system is capable of diffraction limited imagery. The combination is anastigmatic and semi-apochromatic over the limited specified spectral range of correction.

The principal residual aberration is spherochromatism. It is significant to note, however, that the D-light and F-light are well within the Rayleigh limit over the entire field, the C-light at the center of the field. It is possible to correct this aberration by installing a thin two-element achromatic corrector plate at the telecentric stop. However, in view of the monochromatic utility of the system, it was not considered justifiable, although some future application may conceivably warrant it.

There are, of course, other design alternatives available for color correction. From the paper design standpoint, there are many glasses available having unusual partial dispersions which will eliminate the chromatic residuals. However, these glasses are generally characterized by poor physical properties. Glass acquisition is further aggravated by the limitations in melting quality glass in massive blanks sizes of the order required for this application. Moreover, the economics of obtaining these glasses in massive size becomes a major problem.

It is this latter problem which shaped the style of this design. All the glass elements of this design are on the glass line or the near neighborhood of the glass line. They represent the lowest cost, highest quality glass available. The principal area of axial color correction occurs at elements #4 and #5, elements #10 and #11, all other elements being essentially non-dispersive. The principle of symmetry is utilized to correct the lateral chromatic aberrations.

Figure 1 illustrates the Maxwellian view of the system exit pupil, in which 84 rays are distributed for spot diagram calculations.

Figures 2 through 16 give the spot diagrams for 4 field positions and 3 colors. The ring represents the first dark band of the diffraction pattern. In the mean wavelength, the percentage of rays traced falling within the first dark band at 0^{o} is 83%. The extreme long wavelengths, the C-light and greater, are in excess of the diffraction limited case due to spherochromatism.

It is significant to note that the trigonometric traced ray may pass through a circle whose radius is nearly twice as great as that of the first minimum with no resultant loss in resolving power for strongly marked detail.

Therefore, by this criteria as well as the monochromatic application for which the system is to be used, the target specifications have been met in this study.

The lens data formula for the 2:1 reduction printer is contained in Table I. Table II gives the surface by surface third order contributions and the chromatic variation of third order. Slope intercept curves for four field positions, the radial energy distribution in the image and the longitudinal color curves are contained in Figures 17 through 20, respectively.

16" F/2.0 2 X 1
ENLARGING SYSTEM

SCALE: QUARTER

FIGURE 1B

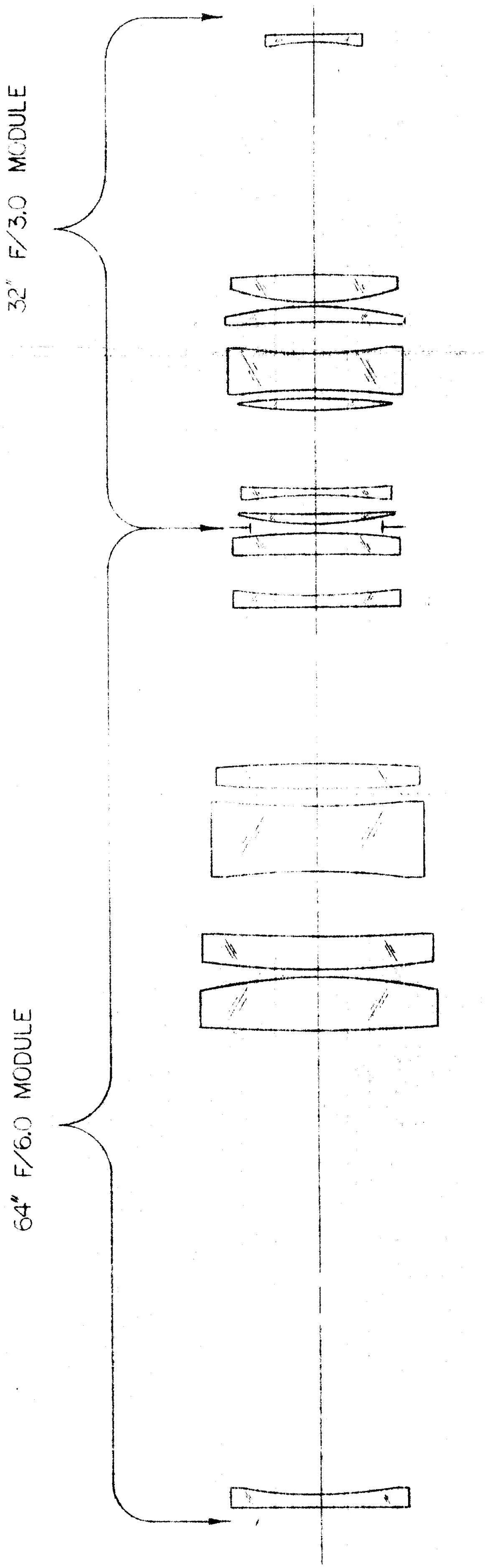

TABLE I

SEMI - APOCHROMAT REDUCTION LENS

LENS FORMULA

Surface	Radius (Inches)	Element or Airspace Thickness	Clear Aperture	Glass Type
1	Plano	.973	20.994	511/635
2	27.217	36.488	20.220	
3	196.188	4.282	20.260	614/595
4	43.105	.264	20.152	
5	55.885	2.725	19.298	620/603
6	222.676	5.138	18.542	
7	57.249	5.082	16.152	720/293
8	118.814	1.198	15.072	
9	104.018	2.141	14.798	511/635
10	80.487	12.066	14.494	
11	Plano	.973	10.162	BaSF-6
12	61.754	3.114	10.174	
13	288.281	1.752	10.542	LaF 2
14	51.337	.487*	10.676	
15	25.668	.876	10.676	LaF 2
16	144.143	1.557	10.602	
17	30.877	.487	10.336	BaSF-6
18	Plano	6.033	10.318	
19	40.243	1.070	10.134	511/635
20	52.009	.599	10.082	
21	59.407	2.541	9.916	720/293
22	28.624	2.569	9.662	
23	111.337	1.362	10.016	620/603
24	27.942	.132	10.384	
25	21.552	2.141	10.866	614/595
26	98.093	18.244	10.892	
27	13.609	.486	10.276	511/635
28	Plano	5.503 (BF)	10.646	

EFL = 16.000 inches

Front Conjugate Distance = 11.006

* Airspace #7 is flexible in dimension, to accommodate an exposure control device.

TABLE I
(cont'd)

Computations based on following indices.

GLASS TYPE	D	F	C
511/635	1.51100	1.51665	1.50860
614/595	1.61400	1.62126	1.61094
620/603	1.62000	1.62724	1.61696
720/293	1.72000	1.73766	1.71309
BaSF-6	1.66741	1.67878	1.66284
LaF 2	1.74385	1.75561	1.73904

TABLE II

THIRD ORDER ABERRATIONS
AND CHROMATIC VARIATIONS
2:1 REDUCTION PRINTER LENS

Surface	B δb	F δf	C δc	E δe	a	b
1	-.0002983 -.0000025	-.0009491 -.0000104	-.0030199 -.0000250	-.0096092 -.0000795	-.0004072	-.0012956
2	-.0011894 .0000166	-.0023397 -.0000533	.0046024 .0001455	-.0365503 -.0008947	.0007097	-.0013961
3	-.0050143 -.0000894	-.0020283 .0001063	-.0008205 .0000990	-.0012143 .0001147	-.0037495	-.0015767
4	-.0007517 -.0000650	.0026415 .0002153	-.0092825 -.0007096	.0675090 .0025196	-.0030377	.0106748
5	-.0016921 .0004166	-.0013341 .0000554	-.0010517 .0000459	-.0069029 -.0000109	-.0032698	-.0025779
6	-.0000002 -.0000006	.0000228 .0000269	-.0023023 .0003767	.0372614 .0015113	-.0000674	.0068110
7	.0019272 .0001597	-.0059062 -.0004611	.0181002 .0013262	-.0806788 -.0041770	.0071894	-.0220329
8	.0028298 .0001045	.0035759 .0000302	.0045186 -.0000890	.0107183 -.0003137	.0072717	.0091889
9	-.0028856 -.0000880	-.0033609 -.0000032	-.0039145 .0001105	-.0088191 .0003403	-.0029263	-.0034083
10	-.0001194 .0000009	.0005690 -.0000002	-.0027120 -.0000208	.0354561 .0006164	-.0013912	.0066309
11	-.0000024 0	-.0000558 -.0000011	-.0012697 -.0000195	-.0289059 -.0002838	-.0004416	-.0100525
12	.0066024 .0002501	.0082822 .0000966	.0103895 -.0001478	.0221795 -.0006251	.0071044	.0089120

TABLE II
(cont'd)

Surface	B db	F df	C dc	E de	a	b
13	-.0004242 -.0000386	-.0018438 -.0001037	-.0080145 -.0001770	-.0276019 .0002524	-.0022925	-.0099646
14	-.0014895 -.0000122	.0028432 .0000539	-.0054274 -.0001614	.0282024 .0008400	-.0053131	.0101421
15	-.0119193 -.0000001	-.0113756 .0002559	-.0108568 .0004860	-.0282033 .0008680	-.0106266	-.0101418
16	-.0033933 -.0003463	.0073751 -.0022709	-.0160291 .0019858	.0276026 -.0019737	-.0045847	.0097643
17	.0528179 .0022086	-.0331282 -.0022709	.0207785 .0019858	-.0221794 -.0019737	.0142088	-.0089120
18	-.0000196 -.0000018	.0002230 .0000145	-.0025388 -.0001059	.0289059 .0005359	-.0008829	.0100526
19	-.0009552 .0000291	-.0022764 .0000732	-.0054248 .0001835	-.0354563 .0002640	-.0027825	-.0066310
20	-.0230844 -.0007750	.0134434 .0008198	-.0078288 -.0006944	.0088191 .0006922	-.0058525	.0034083
21	.0226377 -.0009104	-.0143032 .0008198	.0090371 -.0006944	-.0107183 .0006922	.0145434	-.0091889
22	.0154197 .0011079	.0236270 .0011183	.0362027 .0008366	.0806798 -.0001501	.0143795	.0220331
23	-.0000018 -.0000041	-.0000913 -.0000937	-.0046053 -.0006762	-.0372618 -.0011116	-.0001350	-.0668111
24	-.0135368 .0004923	.0053361 .0002346	-.0021034 -.0002672	.0069029 .0007369	-.0065397	.0025779
25	-.0060146 -.0004240	-.0105676 .0005177	-.0185672 -.0005146	-.0675104 .0001451	-.0060757	-.0106750

Surface	B db	F df	C dc	E de	a	b
26	-.0401153 -.0007168	.0081133 .0009189	-.0016409 -.0003488	.0012142 .0001980	-.0074992	.0015167
27	.0095163 .0000095	.0093598 -.0002103	.0092059 -.0004203	.0365509 -.0009799	.0014196	.0013963
28	-.0023862 -.0000173	.0037965 .0000964	-.0060403 -.0002641	.0096102 .0005969	-.0008144	.0012957
$\sum$	-.0011639 .0009605	-.0003513 .0000579	-.0006155 .0000905	.0000004 .0000388	-.0018628	.0000002

All dimensions in inches.

First line is third order aberration.

Second line is chromatic variation (F - C).

Positive values denote overcorrected aberrations.

TABLE II
(cont'd)

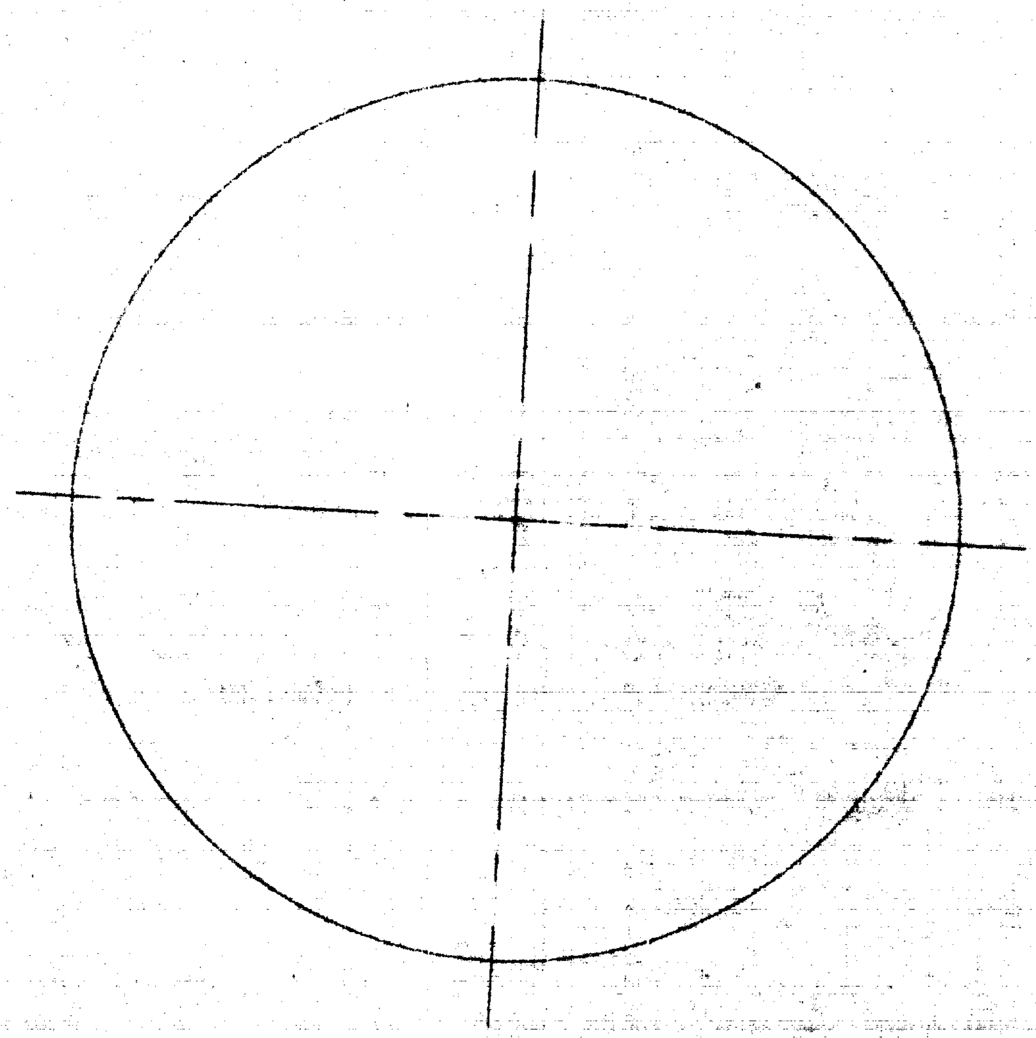

FIGURE 1 EXIT PUPIL

AXIAL

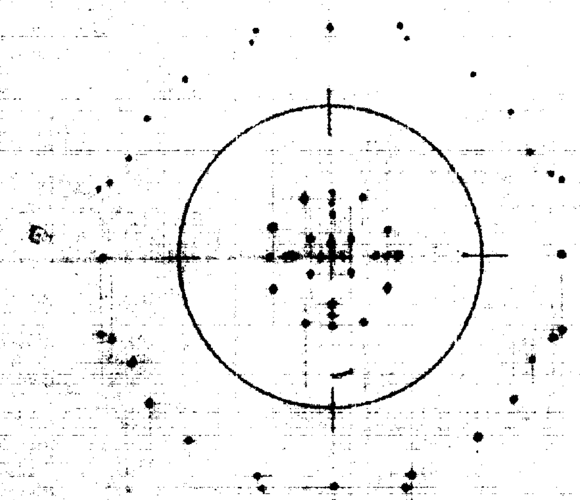

FIGURE 2 - SPOT DIAGRAM - AXIAL BUNDLE - λ=5893 (D-LINE)

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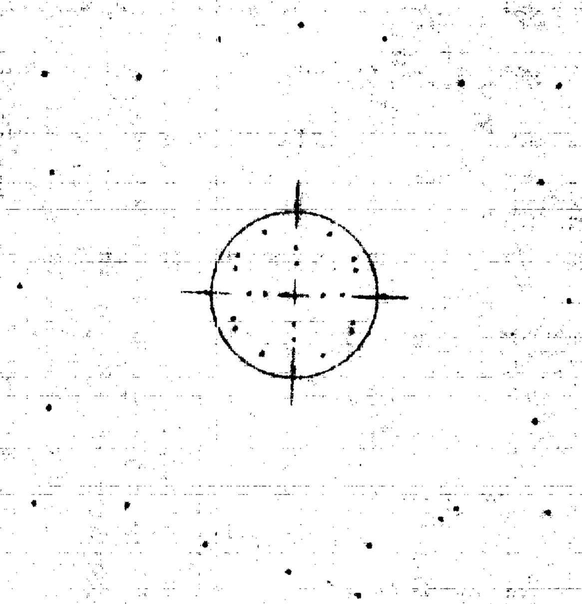

FIGURE 3 - SPOT DIAGRAM-AXIAL BUNDLE-λ=6563 (F-LINE)

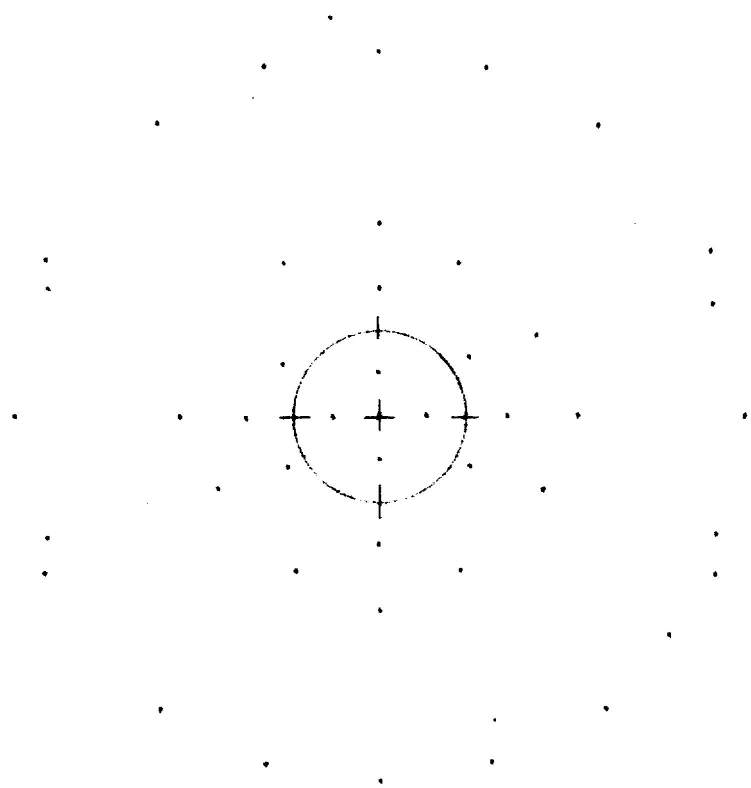

FIGURE 4 - SPOT DIAGRAM - AXIAL BUNDLE - λ=6563 (C-LINE)

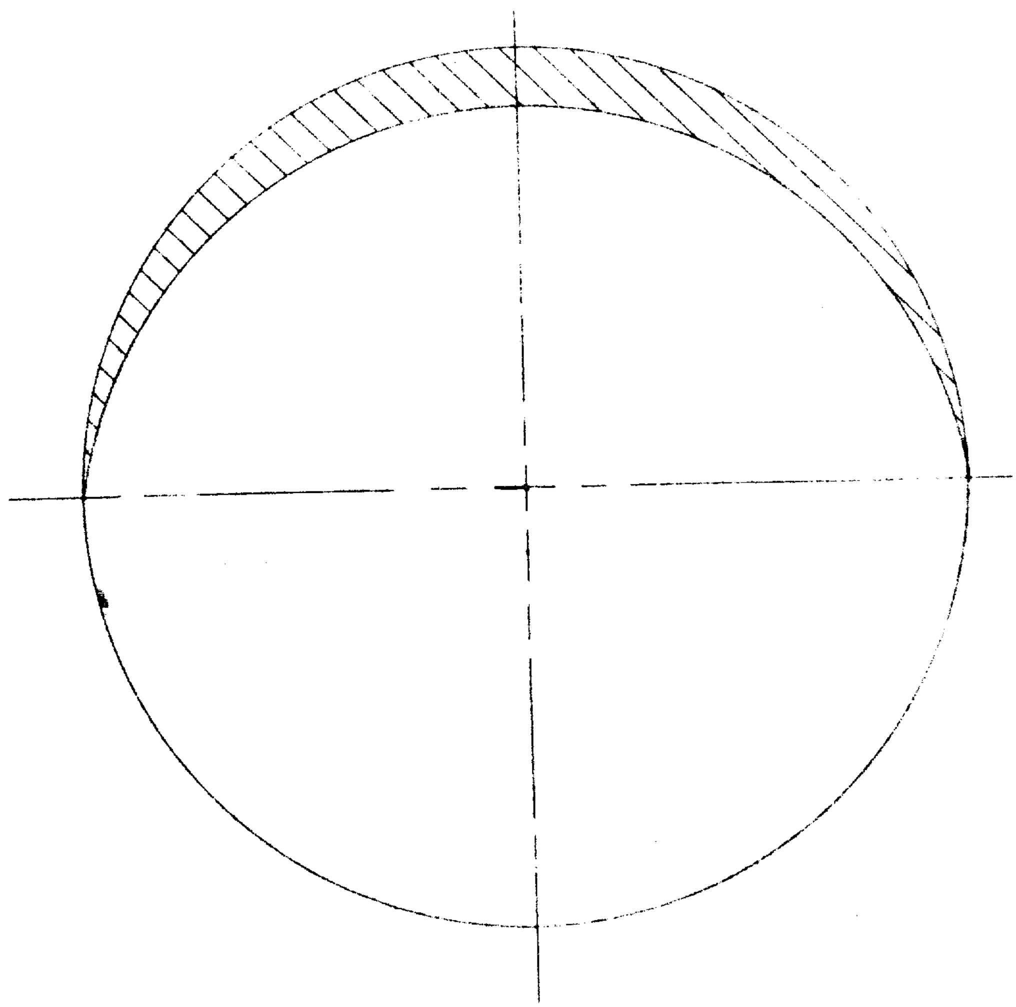

FIGURE 5 PUPIL, 6° OFF AXIS

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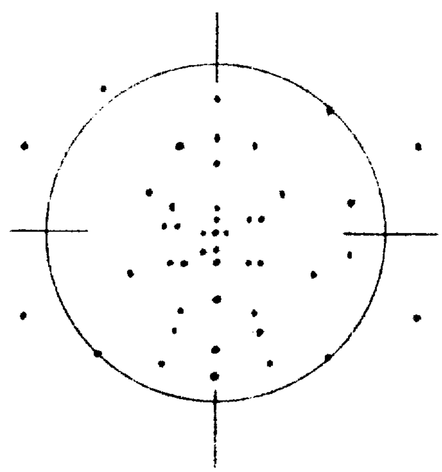

FIGURE 6–SPOT DIAGRAM, 6° OFF AXIS–λ=5893 (D-LINE)

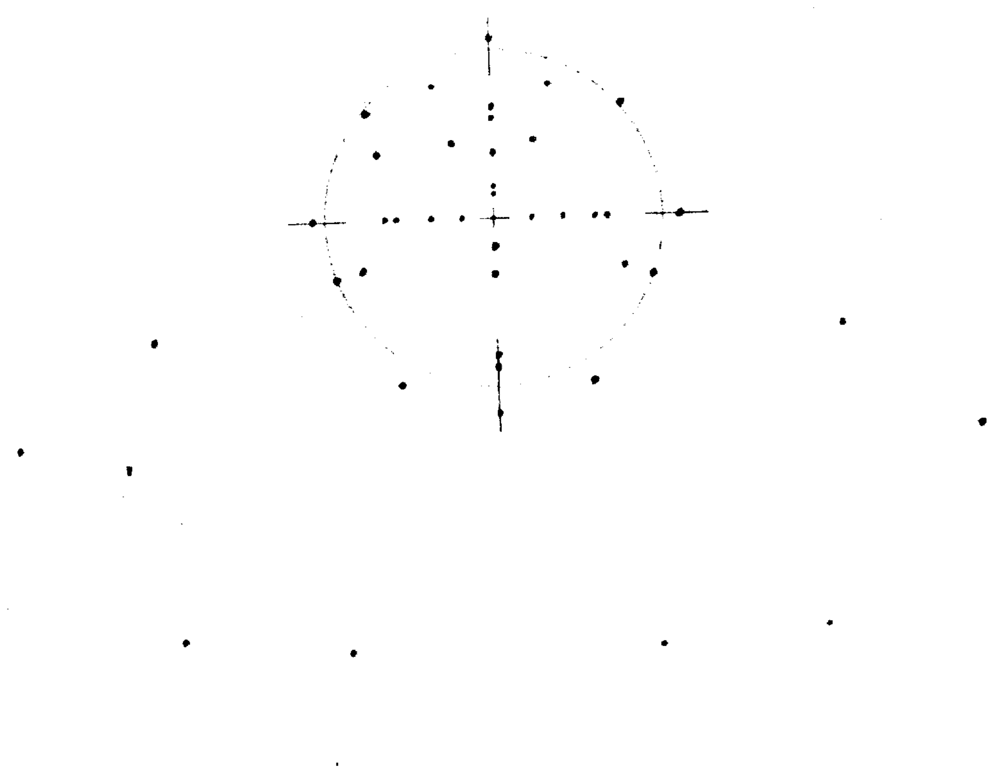

FIGURE 7 - SPOT DIAGRAM, 6° OFF AXIS - λ = 4861 (F-LINE)

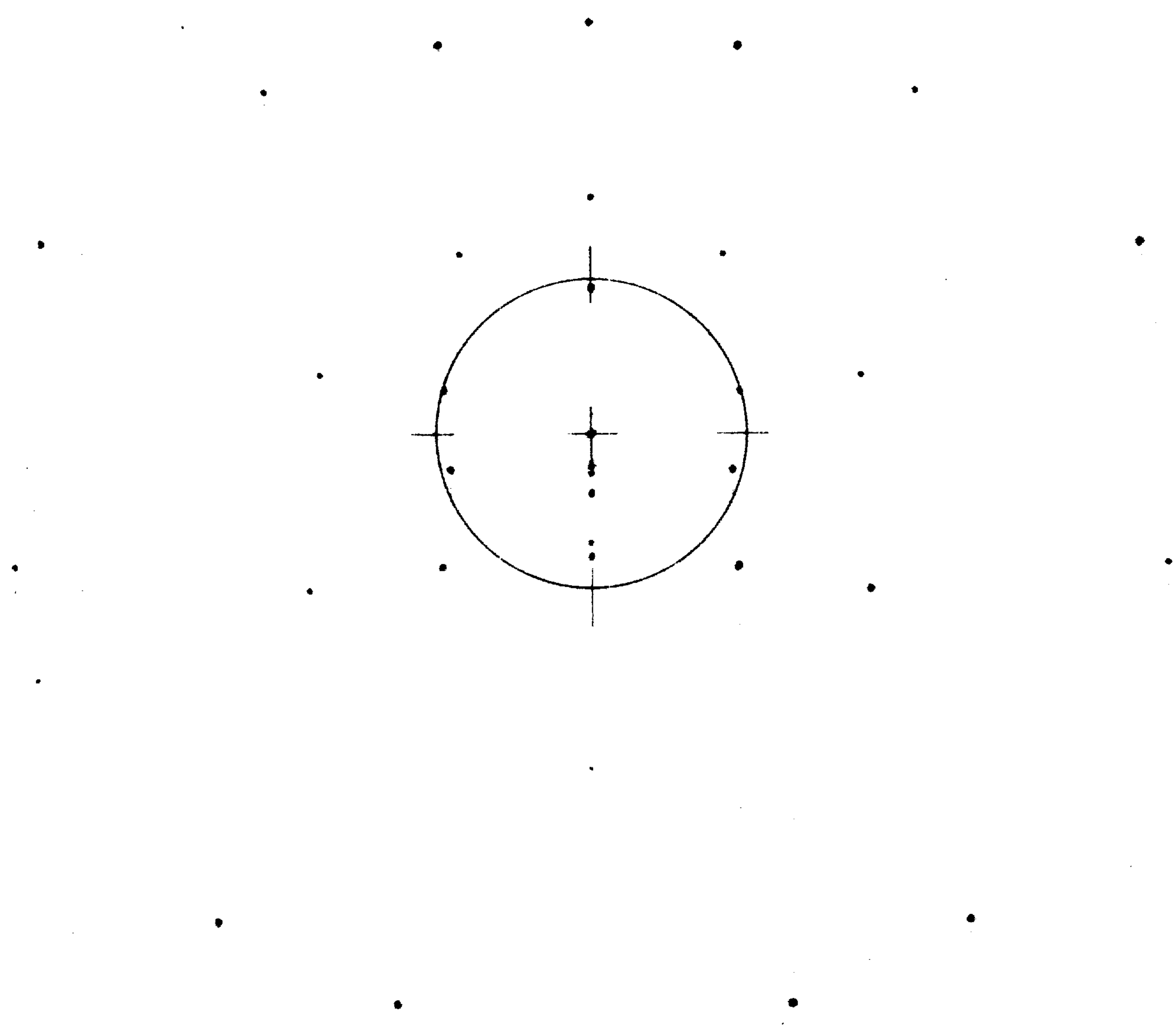

FIGURE 8 - SPOT DIAGRAM, 6° OFF AXIS-λ=6563(C-LINE)

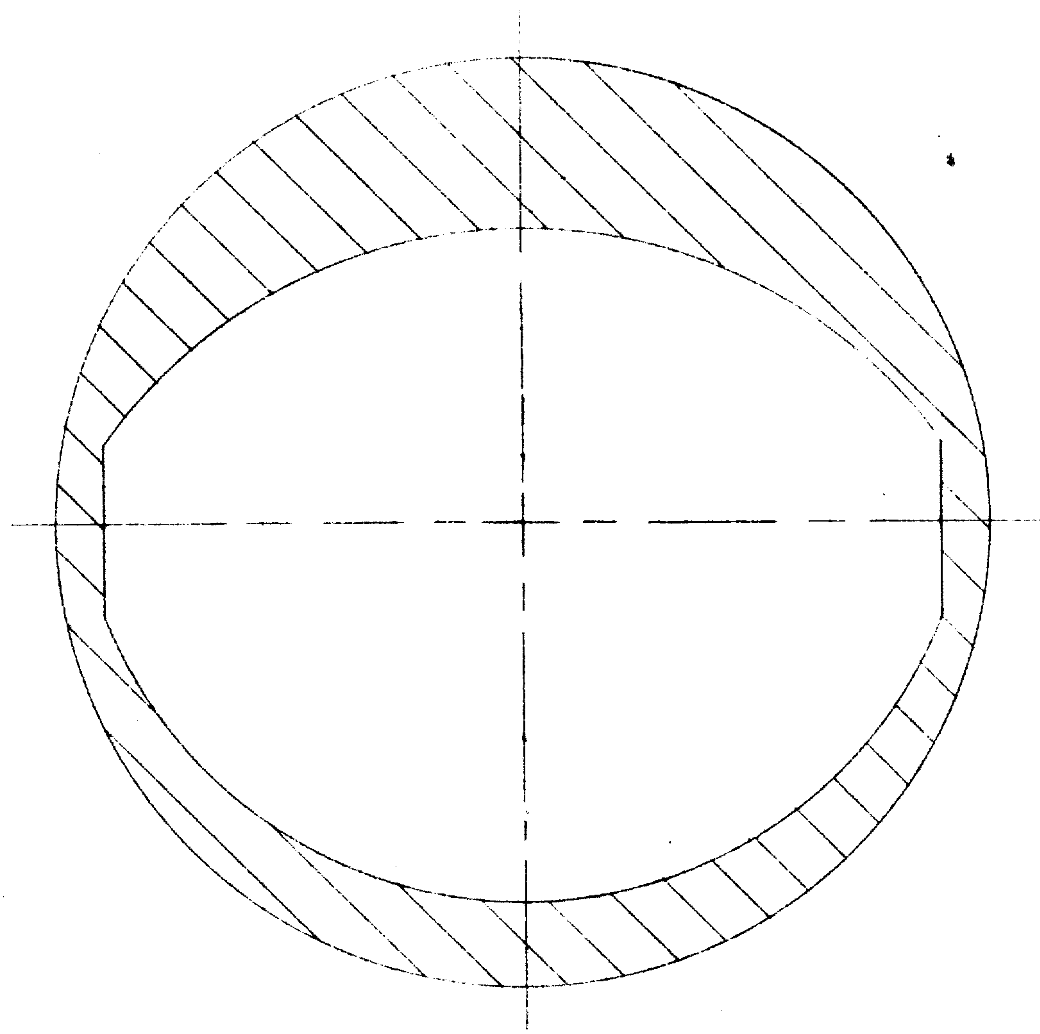

FIGURE 9 PUPIL, 11° OFF AXIS

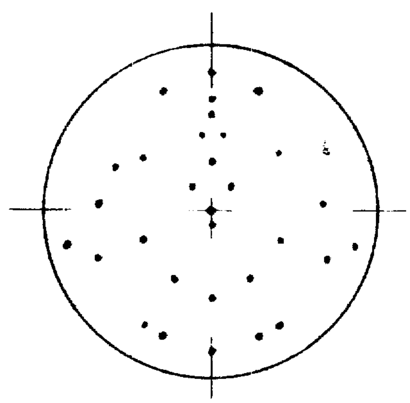

FIGURE 10 – SPOT DIAGRAM, 11° OFF AXIS–λ=5893 (D-LINE)

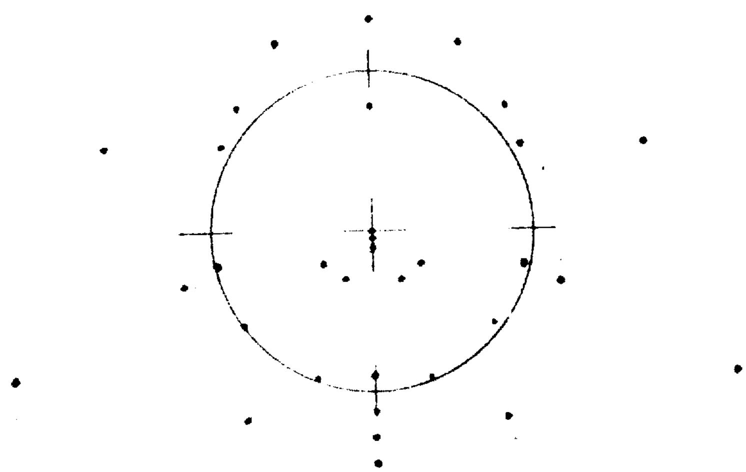

FIGURE 11 - SPOT DIAGRAM, 11° OFF AXIS - λ = 4861 (F-LINE)

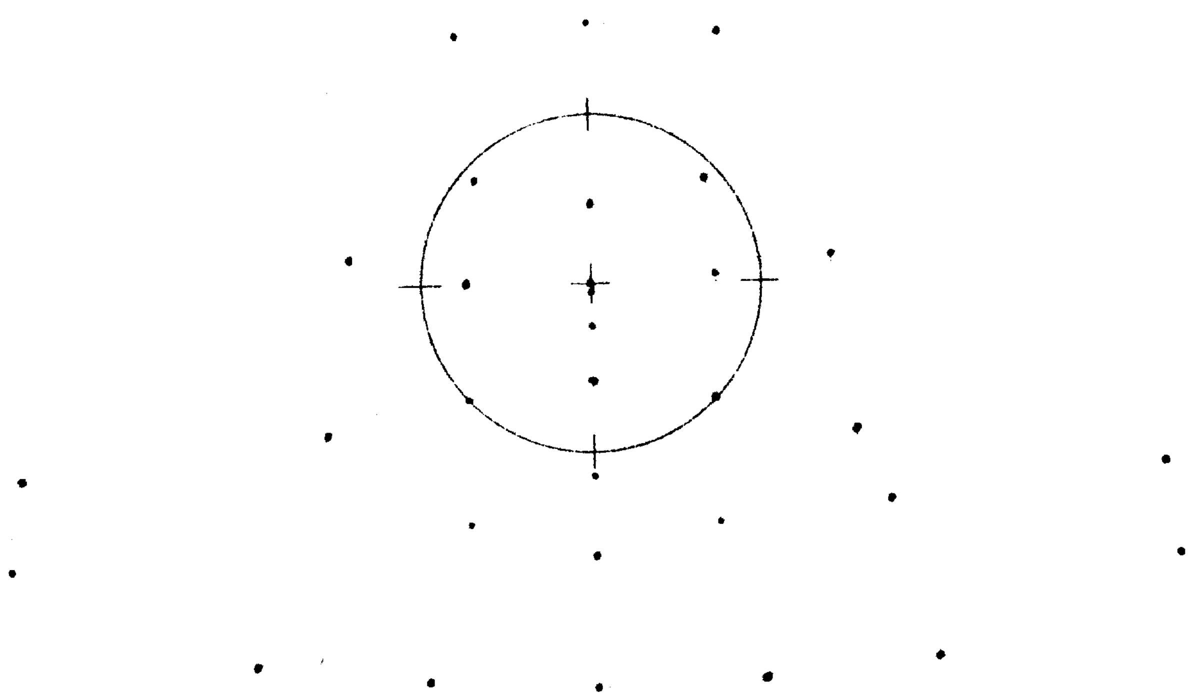

FIGURE 12 – SPOT DIAGRAM, 11° OFF AXIS – λ=6563 (C-LINE)

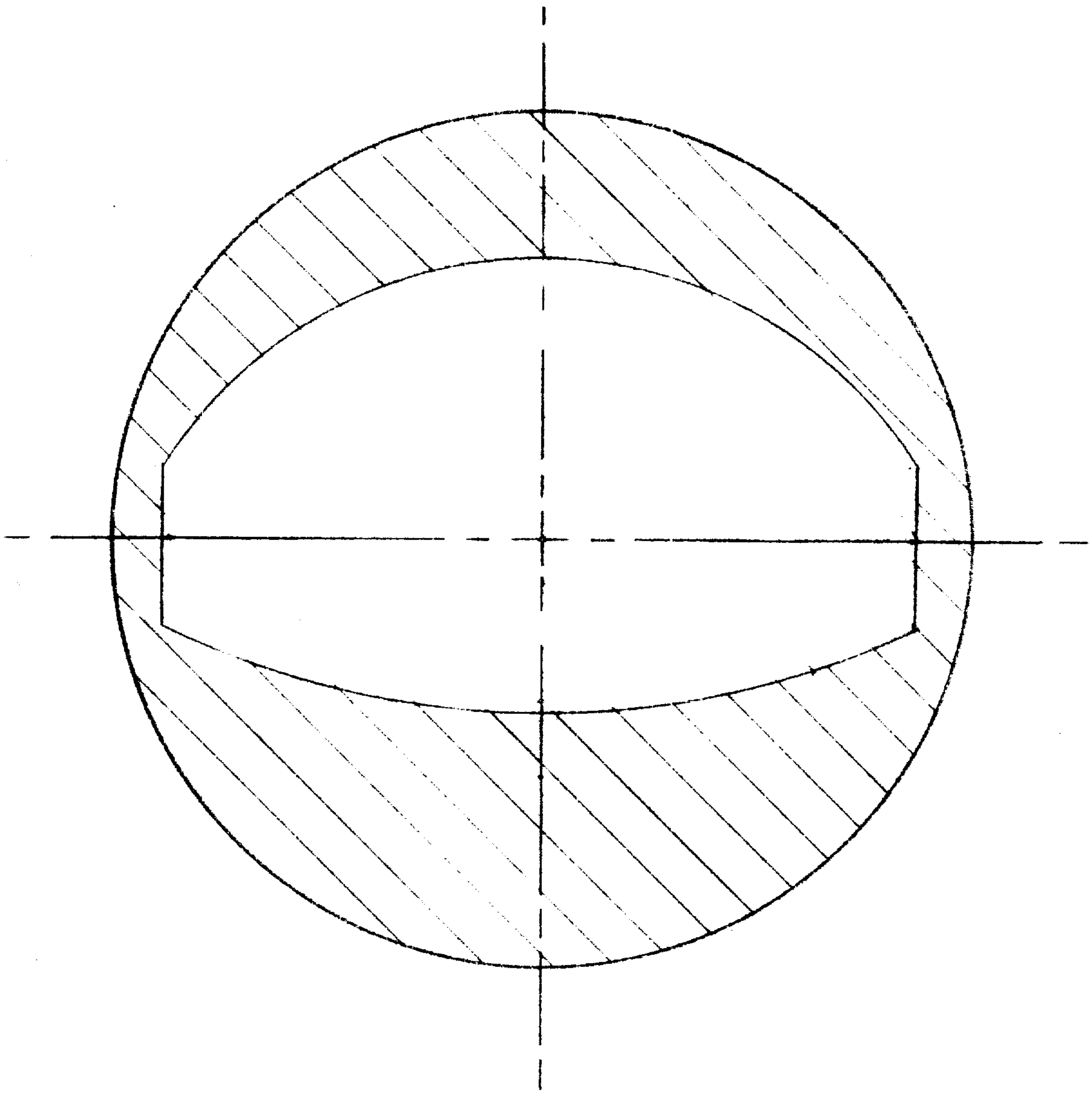

FIGURE 13 - PUPIL 21° OFF AXIS

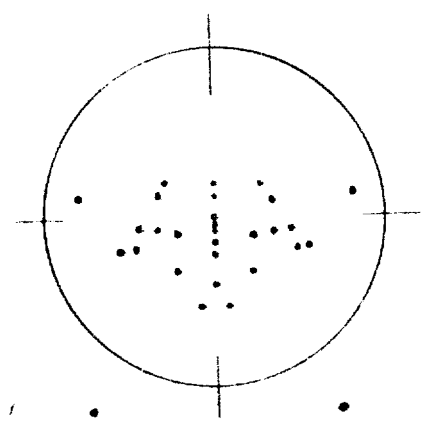

FIGURE 14 –SPOT DIAGRAM 21° OFF AXIS – λ=5893 (D-LINE)

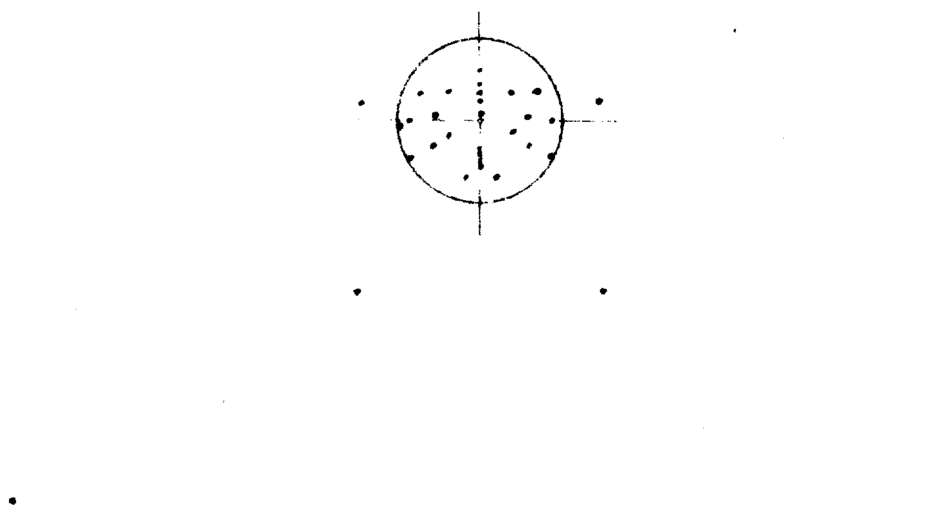

FIGURE 15 – SPOT DIAGRAM 21° OFF AXIS – λ .4861 (F-LINE)

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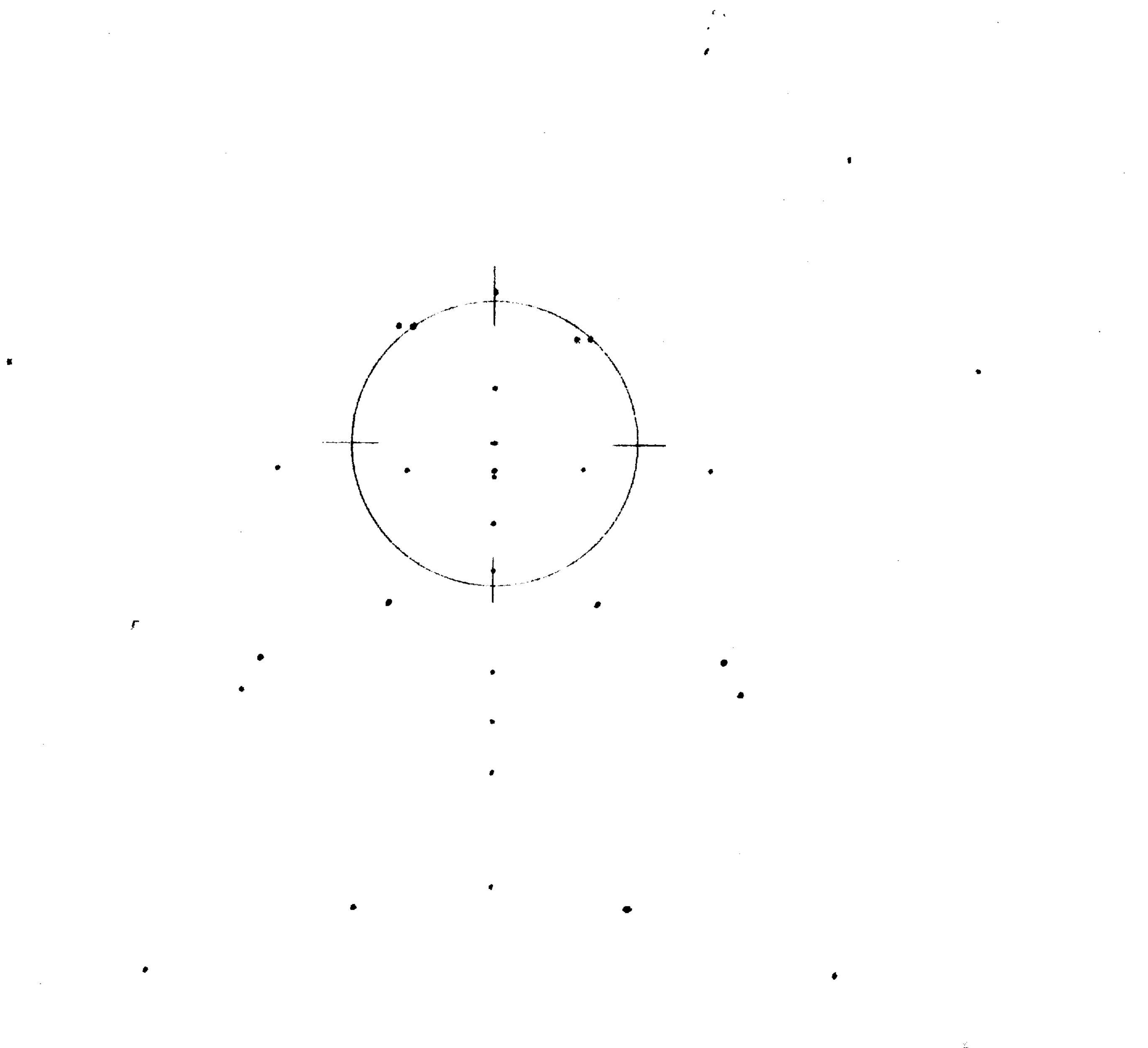

FIGURE 16 — SPOT DIAGRAM 21° OFF AXIS — λ = 6563 (C-LINE)

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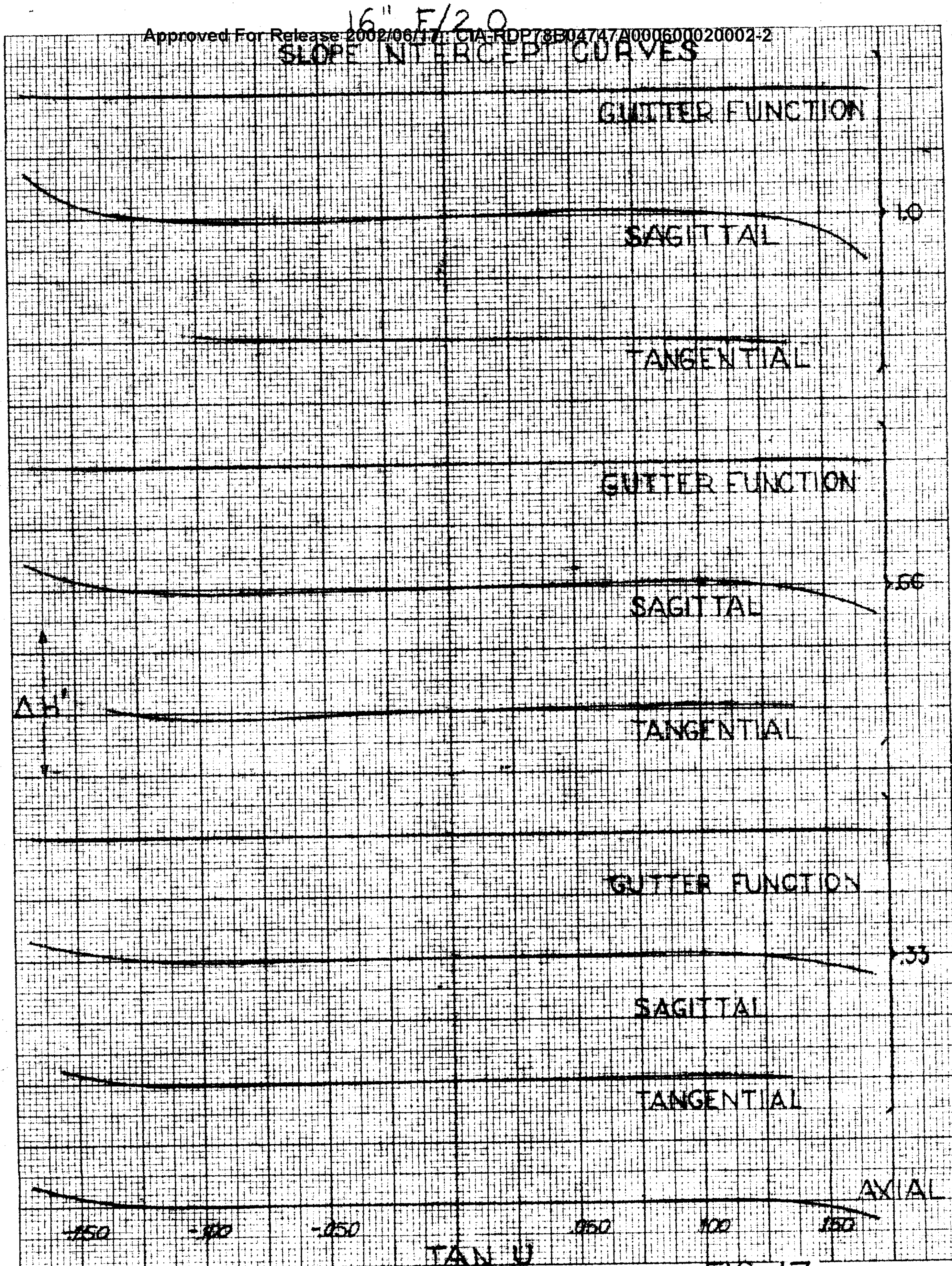
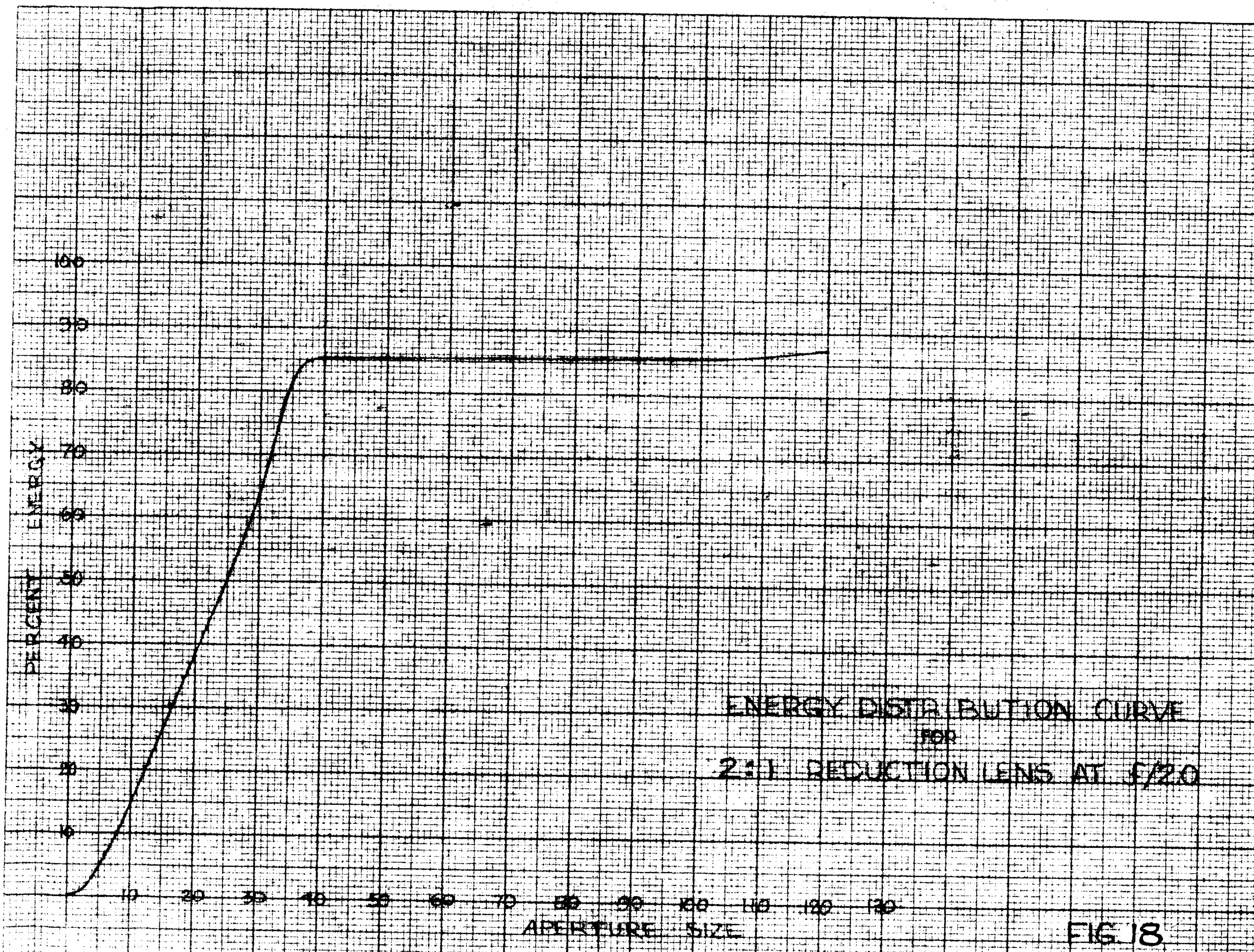

16" F/2.0
SLOPE INTERCEPT CURVES
GUTTER FUNCTION
SAGITTAL
TANGENTIAL
1.0
GUTTER FUNCTION
SAGITTAL
TANGENTIAL
.66
ΔH'
GUTTER FUNCTION
SAGITTAL
TANGENTIAL
.33
AXIAL
-.150
-.100
-.050
.050
.100
.150
TAN U

FIG. 17



ENERGY DISTRIBUTION CURVE
FOR
2:1 REDUCTION LENS AT f/2.0

FIG 18

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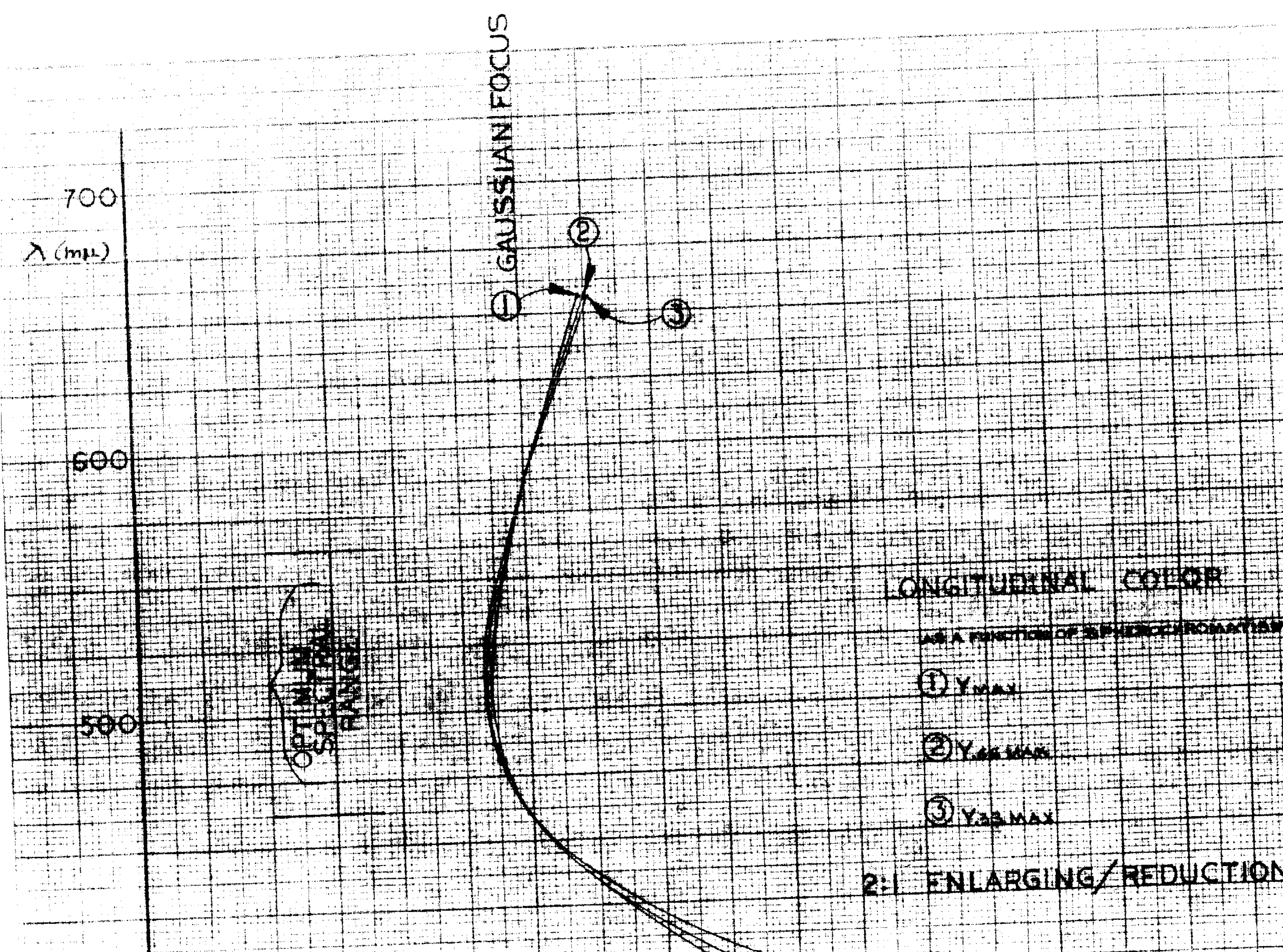
GAUSSIAN FOCUS
① ② ③
700
λ (mμ)
600
500
400
OPTIMUM SPECTRAL RANGE
-.10
-.05
0
+.05
+.10
ΔL.C. (IN)
LONGITUDINAL COLOR
AS A FUNCTION OF SPHEROCHROMATISM
① Y MAX
② Y MAX
③ Y.33 MAX
2:1 ENLARGING/REDUCTION

FIG. 19

SECTION III

CONCLUSION

This report covers the development of a 2:1 Reduction Printer Lens in which three distinct all-refractive lens configurations were considered. One of these, the Petzval form, proved to be successful.

The resolution specification of this contract requires that the optical design, when fabricated, be capable of resolving 200 lines per millimeter under low contrast monochromatic object conditions.

The assessment of the efficiency of such an optical instrument when the reciprocal functions of resolution and contrast are so stated must be determined relative to the diffraction pattern. The lens design, therefore, must approximate the diffraction limited case where, by definition, the geometrical aberrations are small with respect to the diffraction affects.

The computed spot diagrams, which can be shown to have close correspondence with photomicrographs of the actual images, indicate that the design meets the resolution requirements for the monochromatic case.

The diffraction limited imagery extends over a relatively broad spectral range by virtue of the Rayleigh 1/4 wavelength criteria, although a discernible loss in definition must be expected when the lens is utilized over the full extent of the spectral range.

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APPENDIX

The optical design configuration developed has inherent versatility for the generation of a large family of reduction/enlarging lenses utilizing a building block concept.

The front and rear conjugates may be envisioned as basic modules capable of attachment one to the other about a telecentric stop.

The design manipulation of the focal lengths and relative apertures of the basic module designs are the key variables required to achieve any arbitrary enlarging/reduction system.

In order to preserve the performance quality of such a system we must restrict ourselves to the following general rules:

1. The telecentric condition must be maintained.
2. Any arbitrary system effective relative aperture has a maximum of F/2.0 without redesign.
3. The speed of any arbitrary short module shall not exceed F/1.3.
4. The equivalent focal length of any arbitrary system shall be as great as possible.

Moreover, it should be stated that the resultant magnification of such a system configuration is equal to the ratio of the focal lengths of the modules and that the effective relative aperture of the combination is equal to the ratio of the F/ numbers of these modules.

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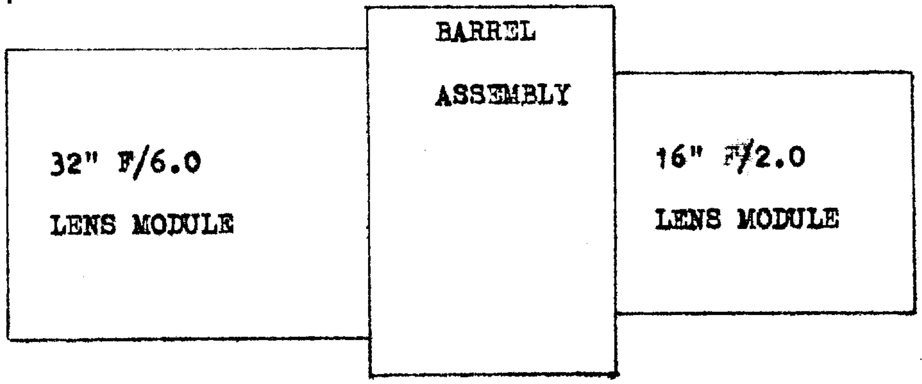
An example of modules which are compatible with regard to entrance pupil diameter might be generated to illustrate the implied economic gain derived in these convertible magnification modules.

Consider the short module of this application: 32" EFL F/3.0 for 9" x 9". The lens formula of this module might be conveniently scaled to 16" EFL F/1.5. This new module, when attached to the former module, will yield an 8" EFL F/2.0 reduction/enlarging lens for 9" x 9" to 4-1/2 x 4-1/2" formats.

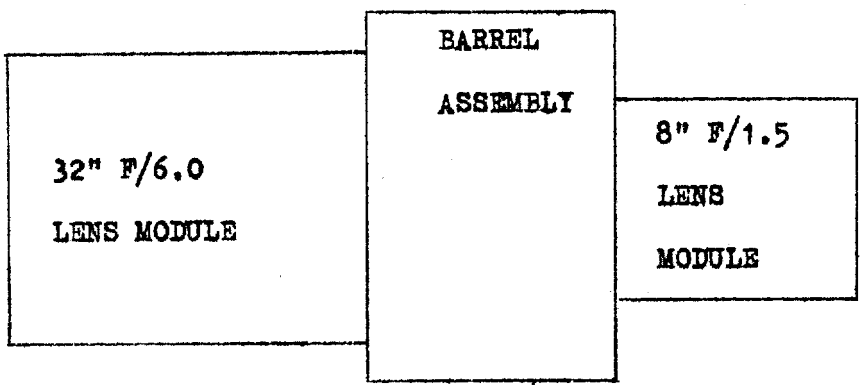
This example demonstrates what might be termed format versatility.

Magnification versatility is achieved in much the same way. The basic short module of this contract design may be directly scaled to an 8" F/1.5. By combining this module with the short module, we obtain a 4" F/2.0 whose object and image formats are 9" x 9" to 2-1/4" x 2-1/4 respectively. Figure 20 gives a schematic diagram typical of this convertible approach.

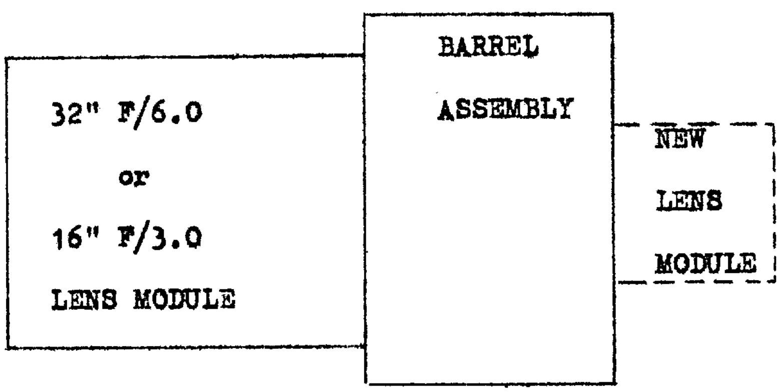
In conclusion, it might be said that a three-module package will provide at least two distinct enlarging/reduction printer lenses, the performance of which will be diffraction limited in each case for the monochromatic condition.



2 to 1 ENLARGING SYSTEM



4 to 1 ENLARGING SYSTEM



CONVERTIBLE MAGNIFICATION MODULAR COMBINATION

FIGURE 20